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No. 782.

SCIENCE AND ENGINEERING.

ADDRESS AT THE ANNUAL CONVENTION AT SAN FRANCISCO, CAL., JUNE 30TH, 1896.

By THOMAS CURTIS CLARKE, President Am. Soc. C. E.

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Engineering, in its broadest sense, is the practical application of such discovered laws.

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The word "evolution" simply means "growth," and there are but few now left who cling to the idea that God created his universe as we see it now. We believe that the world and all that is in it grew from the simplest forms, just as a tree grows from its seed, and the most

highly organized animal from a germ-cell. We see that in all cases this growth is from the simple to the complex, from a state where the parts are few and like each other, to a state where the parts are many and unlike each other, yet all working for a common end.

Not only the universe, this planet, and all its animate and inanimate things, but also all social institutions and professions, and civilization itself, develop under this same law of evolution or growth from the simple to the complex

Herbert Spencer, the great master of this great subject, has shown that our present professions, law, medicine, architecture and engineering, have all developed from the clerical profession. A little reflection will show that this must be so. A profession requires special education and instruction on the part of its professors. In early times there was but one educated class—the clergy—and they were the only ones who knew enough to be lawyers, doctors, architects and engineers.

It is easy to see the connection of law and religion, as law was originally based on equity, and equity and morality form part of religious duty. Disease, in ancient times, was thought to be either an affliction sent by God, or possession by the devil; hence the clergy were the proper medical men.

An art requiring so much technical skill as architecture was originally practiced by the clergy, as temples, churches and monumental structures naturally fell under their supervision. The great cathedrals of the middle ages were built by the higher clergy of those days, among whom William of Wykeham and Abbot Suger are deservedly famous.

A curious survival of this is found among architects even now, who call everybody but themselves "laymen."

The earliest engineers of whom we have any record were the priests of Egypt, whose wonderful works in masonry are surpassed by no masonry works of our days; and the only way in which we can show our superiority is by our greater skill in the use of metals.

Civil engineering did not become separated from the clerical profession until in much later times. We know this from the Latin word "pontifex," which means a bridge builder and also a priest, and from which the words "pontiff" and "pontifical" are derived. The Pope of Rome is still styled Pontifex Maximus, Supreme Pontiff, or chief bridge builder, whichever you please.

The building of a bridge was considered such a remarkable feat, that the name pontifex became the highest clerical title.

Men of inventive talent, not clergymen, displayed much skill in inventing and operating engines of war, hence the name engineer. Civil engineer was a later title, and thus indicates a later development.

Civil engineering is the youngest of the professions, and the reason of its late evolution is this, if engineering be the application of Nature's laws, there could be no engineering profession until these laws were discovered. These discoveries did not come until late in the world's history. It was not until the human mind had become impressed with the constancy of the order of Nature, and that chance had no place in it, that the reign of law began, and men then strove to discover what were those necessary sequences of cause and effect that we call the laws of Nature.

The progress of science was much retarded by the conservative spirit. The works of Copernicus were suppressed. Galileo was imprisoned, and Bruno was burned. Even Newton's splendid discovery of the laws of gravitation was not accepted by those pious persons who feared lest it might detract from the majesty of the Almighty to assume that he worked by law and not by caprice.

Fortunately the world had grown wiser in Franklin's day, and readily believed that the tremendous flash of lightning could be imitated by rubbing a glass bottle with a silk handkerchief, or be drawn from the clouds by a boy's kite.

Men's minds became open to receive knowledge. A common proverb says "One thing leads to another." Hence it is that science in this century freed from the stigma of impiety, and using instruments of the most marvelous precision, has been able to make so many new discoveries.

Some of those which have been made, even in my day, are as follows:

The evolution of life has been shown by Darwin in his doctrines of variation and the survival of the fittest.

The modern geology, which we owe to Lyell, teaches us that this globe came to its present condition by the operation of natural laws still in force, and not by a series of catastrophes. Its vast antiquity, even since the appearance of man, has also been demonstrated.

The researches of Helmholtz, Joule and Faraday have shown the

identity of light, heat, electrical and chemical action as transformations of energy; which has led to what is probably the most comprehensive scientific discovery of this century, the conservation or indestructibility of energy, binding into one law all dynamic action. This shows that power cannot be crêated, but only transformed, and proves the utter absurdity of Keeley motors and of perpetual motion.

Kirchhoff and Bunsen have given us the spectroscope, which with equal certainty detects the infinitesimal part of a grain of some substance in the flame of a lamp, and also shows the presence of our familiar gases in the light of a star so far away that the ray which now reaches us started on its way before the beginning of Egyptian civilization. The spectrum analysis has created the new astronomy, proving the uniformity of matter, and extending the reign of law all over the visible universe, of which we are but a mere speck.

Such are some of the later discoveries of pure science. Equally wonderful are the discoveries in those branches of science which can be applied to the use of man, and in whose application the engineer takes no mean part.

We have now the new chemistry, which is synthetic as well as analytic. In other words, it not only investigates the composition of bodies, but has learned how to create them by its own processes, such as the invention of aniline dyes, oleomargarine and the economic production of aluminum.

It has revolutionized nearly every art and manufacture. The engineer Bessemer, in the art of metallurgy, has given us the modern steel, which has done as much to lessen the cost of transportation as the invention of the locomotive itself.

Another very important late discovery in medico-biological science is that of the presence of those infinitesimal beings called micobes, which, although so small, exercise such a great influence upon human life and health.

Here the labors of the engineer have come into play and have shown us how to purify water by sand filtration. The experiments of the engineers of the Massachusetts State Board of Health have shown us that sewage, being destitute of oxygen, must be applied to filter beds slowly and intermittently from above, so that air can follow it down and aerate the purifying microbes, and keep them alive to do their work. By this means the worst water can be made chemically pure.

By far the most striking application of science in this century has been in electricity. Morse and Henry have given us the telegraph; Bell, the telephone; Edison, the incandescent lamp; Tesla, the alternating current, and McFarlan Moore hopes soon to give us artificial daylight from glass tubes, in which are no loops nor carbons, but only repeated interruptions of an electric current in a high vacuum. It has also given us the separation of metals from their solutions, and the economic transmission of energy, which has re-created our street railways, machine shops and manufactories, and may soon supersede steam locomotives, where frequent stops are necessary.

Its new discoveries come so fast that one can hardly write them down. Even while preparing this address a great discovery is announced. It has been the dream of investigators to find some means of producing electrical energy from coal without combustion. We now hear of a very simple process by which over 80% of the potential energy of carbon can be converted into electrical energy by causing the oxygen of the air to combine with carbonaceous material, through an intervening electrolyte, preferably melted caustic soda, according to Prof. Cross of the Massachusetts Institute of Technology.*

Assuming that this is true, we may say positively that this discovery will not be of value until the engineer has put it into such practical shape that it will be commercially successful. It may take the place of chemical batteries, but that it can supersede the steam boiler, where great power has to be produced, seems doubtful.

The steam boiler has never had a fair chance until lately. Fuel was crammed under it by ignorant stokers, and the combustion was imperfect for want of oxygen. The scientific engineer has now applied a system of mechanical stoking, which develops much more energy from a pound of coal.

To return from this digression, we may say that electrical discovery has created a new branch of our profession.

The discovery of the X rays is but in its infancy. It can show our bones, but has not been able to penetrate a steel eye bar and show the

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* Sodium hydrate is melted in an iron pot and a carbon cylinder is immersed in the molten material. Air in fine jets is blown through the hydrate. The oxygen from the electrolyte combines with the carbon and an electrical current results from the direct oxydation of the carbon, without any material accompanying generation of heat. The supply of air constantly regenerates the hydrate by supplying fresh oxygen to replace that which has entered into combination with the carbon.

bridge engineer any hidden defects. It seems probable that its application to incandescent lighting is near at hand. The engineers are working at this problem.

Little time is left to speak of military engineers, who are well represented in our society. By them the laws of Nature are applied for the defence of mankind, without which the arts of peace would avail but little.

Experience in the last great wars has shown that that nation which has made the greatest advances in engineering is the most formidable in war. It has been well pointed out by the President of the British Institution of Civil Engineers that all improvements in modern instruments of both attack and defence are the work of engineers. High-power guns and armor-plates, repeating rifles and torpedoes were invented by engineers.

Engineers are now developing and improving a very old invention, the submarine boat. Modern discoveries have furnished it with aids which appear to at last make it practicable.

It can now carry its motive power for use in action in storage batteries. Improvements in handling compressed air make breathing possible. Electric wires can control the discharge of high explosives. If its direction can be controlled, it will revolutionize naval warfare.

The battle-ship will have to be designed anew so as to carry several of these submarine boats on her deck. They are torpedoes with men inside of them able to direct them intelligently and evade any nets or other protection that the battle-ship may have.

For harbor defence a larger class can be used.

Before the close of this century we may see another new branch of engineering. Through the labors of engineers man has extended his dominion over both sea and land. Through the labors of engineers he may soon extend his dominion over the air, and aviation engineers may be as numerous as mining engineers now are.

Such are some of the later discoveries of science. Each new discovery leads to still another, and what we know now is as nothing to what we will know in coming years.

All the great discoveries of science have been made by the application of what is called the scientific method of investigation. This is as necessary to the engineer as it is to the investigator of pure science.

Unless he is equipped with it and understands its use he will always occupy a subordinate rank instead of taking his true place as a master of creative science, which I shall show that engineering really is.

Scientific method consists of observation, deduction and experiment.

It has been well said that a healthful skepticism is the parent of observation. Men are naturally lazy, and it is easier to take things for granted than to observe and find out for one's self.

In deduction, we must beware of hasty conclusions. We must be careful not to be deceived into thinking one thing is caused by another because it comes after it. Unscientific persons think that changes of weather are caused by the moon, and bi-metallic philosophers imagine that the kind of coinage with which they buy or sell things affects their value.

On the other hand we must not be deceived into thinking that one thing has no connection with another, because we do not see that connection.

There was a common proverb in England that Tenterden Steeple was the cause of Goodwin Sands, a dangerous quicksand near the mouth of the Thames that has swallowed many vessels. Common people believed this. The wise called it a vulgar superstition, or possibly a coincidence. Lately a scientific observer examined the archives of Tenterden Church, and found there documents showing that a fund, whose revenues had been applied toward maintaining a dyke shutting off a certain arm of the sea, had been diverted by the Abbot of Tenterden to build a steeple for his church. The dyke being neglected for want of money, the sea burst in and caused the Goodwin Sands. So, the vulgar proverb was right after all.

This illustration shows how necessary it is not to draw hasty conclusions, but to sift the facts after collecting them, rejecting those that have no bearing, and taking great care not to overlook or reject those that are of importance.

In forming a theory to account for the phenomenon, one must be very patient and get all the facts first, and not form the theory first and then try and find facts to fit it. This is the pit which scientific men too often dig for themselves and fall into.

The first step, after forming the theory, is to test its truth by renewed observation and by careful experiment, which Huxley calls an

artificial observation of facts. The art of experimenting is not to be learned in a day, but should form the apprenticeship of the engineer.

When a man, having formed a plausible theory, and having found it corroborated by experiment, suddenly runs against some obstinate beast of a fact that upsets it altogether, what shall he do? Shall he abandon the theory, ignore the fact, or go on patiently looking for newer facts? This is the test which shows whether he is imbued with the true scientific method or not.

Cervantes showed great knowledge of human nature when he describes Don Quixote breaking his helmet by a blow of his sword, and then patching it up again. The Don raises his sword to strike it again, pauses, drops his sword, and finally concludes that the helmet is strong enough after all.

True science begins with the use of mathematics and the invention of instruments of precision. Astronomy began to be a science with the invention of the telescope, and engineering with the invention of some kind of leveling instrument.

A science becomes complete when its predictions can be verified.

Electricity became a complete science when Franklin's prediction that his lightning rod would protect from the electric flash was found to be true.

Engineering became a science when the first stone arch carried its load in safety.

How shall our profession be instructed in the scientific method? In past times every one had to find it out for himself as best he could.

Fortunately we have now an abundance of technical schools, in which those intending to be engineers can be trained both mentally and physically in the very things that they ought to know. They can be trained in mathematics and the physical sciences; while in chemical, physical and electrical laboratories they can be taught the essential arts of experimenting. They learn the use of delicate instruments, and the art of drawing.

Already has been felt in our profession the great influx of young men, trained and cultured in all these things. These schools rank as high, and some think even higher, than the older schools of law and medicine.

It must be clear that the value of the training and instruction

which these schools give depends greatly upon the character of their professors. We sometimes hear sneering remarks upon the engineering of professors, when some of them have attempted to design and execute works for which their experience had not qualified them. Clearly, this is the fault of the individual and not that of the class, who are a most able, competent, learned and painstaking set of men. We should look upon them with the highest respect, and aid in every way in helping them to keep in touch with the profession, by sending them copies of our latest plans, specifications and photographs of executed works. We should not be afraid, also, to tell them of our mistakes (for the best of us are but mortals), and aid in filling that vast and useful volume which should contain what we do *not* know about engineering.

Looking at the great numbers of young men who are yearly graduating from the technical schools and entering the ranks of our profession, the fear has sometimes been expressed lest there may not be room for all.

Let us look at the great number of divisions into which engineering, following the general law of evolution, has become, and is still becoming, specialized, and see if there is not yet ample room.

Civil engineering is divided into structural, mechanical, electrical, metallurgical, hydraulic, mining, agricultural, chemical, sanitary, municipal, highway and railway engineering. These classes are again subdivided; as hydraulic engineering into canal, harbor, water supply, power, storage, and irrigation engineering. Railway engineering is divided into bridge, foundation, track, signaling, locomotive and car engineering.

Such specializations come constantly to meet new wants. Thus, we now see developing a special class of engineers created by the great value of land in cities, calling for very high buildings, and requiring experts to design their metallic frames and their foundations, made complex by their limited spaces, and the necessity of avoiding encroachment on others.

The general principles of engineering govern all these special applications, and may best be described in the words of Bacon: "Nature can be controlled only by obeying her laws."

Some persons confuse civil engineering with structural engineering. We read in the prospectus of one of our technical schools that courses

are given in mechanical, mining, electrical and civil engineering. What is meant is structural engineering, or the art of constructing earthworks, piers, walls, dams, bridges, roofs, viaducts, etc.

The term civil engineering has a much broader meaning, and comprehends all engineering except military and naval. It includes all useful works of sufficient magnitude and intricacy to require scientific method, knowledge and skill in their construction. The civil engineer's true position is similar to that of the architect, who commands the services of many different professions and handicrafts. Mechanical and electrical engineers and many others aid him in their several lines, but from him comes the comprehensive design, and he alone is the director-general of the works.

Such is the position claimed for civil engineers in Britain and on the Continent of Europe. The members of our Society should claim it here, and not only claim it, but show that they are capable of filling it. There is but one way in which they can do this, and that is by showing themselves masters of scientific method and knowledge.

In no other way can the vast interests committed to their charge be safely protected. If the engineer has it, and knows how to use it, we shall hear no more of bridges breaking down, dams being washed away, foundations settling, or guessing at the cost of ship canals, those scandals of the profession.

The war between theory and practice has nearly come to an end. We now recognize that either without the other is not of much value. The practical man is one who has had experience in his own special line, and within his narrow limits he is not likely to make mistakes.

The theoretical man without experience is a dangerous guide. Hence we wisely treat the young man, trained only in the schools, as an apprentice, and make him follow instructions until he gets experience. When he has got it, he rises very fast, and soon becomes a master, and in the race of life passes the "rule of thumb" man.

This is the report which we get from the officers of railways and manufacturing corporations, and from chief engineers, all uniting in preferring the trained man.

The progress of civil engineers in the future will be far greater than it has been in the past. Civil engineers will take a much higher rank in public estimation than they have done, and greater emoluments will follow.

Engineering is the great creative science. It has created a new nature governed by Nature's laws, but one which would soon disappear without the support of the engineer. Just as art creates new bodies of men and women, fairer than those of Nature, and literature creates new characters, as alive and real as the people we meet in the street, so does engineering create its new world.

The locomotive is a draft horse, excelling in power, speed and endurance a thousand of Nature's build.

The bicycle is a faster saddle horse, eating nothing but a little oil, and asking only to be kept clean, and that its circular hoof shall be cured of punctures.

The aviation machine, if we get it, will be an improved bird; the ocean steamer is a fish set at work.

The idle river rolls on for thousands of years. The engineer harnesses it with his turbines and makes it work, either on its banks or at a distance through dynamos and wires.

These very electric wires by which we transport sound and energy are nothing but an extended system of nerves.

Great deserts lie uninhabited. The engineer builds his irrigating dams and canals, and the desert blossoms like the rose, with every variety of flower, fruit and grain.

The dreadful pestilences which once devastated the earth have been almost stopped by the sanitary engineer. The engineer has even shrunk up the world itself with his railways and telegraphs. Magellan took over a thousand days to go around the world; when the Siberian railway is completed, it can be traversed in less than fifty.

Shakespeare, with his wonderful prevision, makes Puck say that he will put a girdle round about the earth in forty minutes. This was nearly accomplished at the electrical exhibition in New York on May 16th, when telegrams were sent half around the world and back, a distance of 27 500 miles, in 47½ minutes.

I have thus attempted to trace the evolution of the engineer from the early days when he knew but little (but what he did know he knew well) down to the end of this nineteenth century whose wonderful achievements in all branches of science have made it absolutely necessary that the engineer should be as thoroughly equipped with scientific method and training as are those who have made these discoveries.

Standing, as I do, near the close of my professional career, I address not only to the members of this Society, but to all engineers wherever they may be, this solemn warning—you cannot afford to be ignorant!

When science—the accurate knowledge of what others have done—and experience—the knowledge of what we ourselves have done—are united in the same person, then we may truly say that we have seen the evolution of engineering from a craft to a profession.